PONDEROSA PINE SEEDLING RESPONSE TO SUPPLEMENTAL IRRIGATION, IRON CHELATES AND NITROGEN FERTILIZATION TREATMENTS APPLIED AT THE ALBUQUERQUE FOREST SERVICE NURSERY

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INTRODUCTION

Seedling production at the Albuquerque Forest Service Nursery has been difficult because soil conditions are not within standards considered optimum for conifer seedling growth. Soil organic matter is low, less than 1%, pH is above 7.5 and soils contain excessive amounts of clay and silt in some production areas. Because seedlings grown before 1982 showed symptoms of lime-induced chlorosis and environmental stress, a cooperative project was initiated to determine the ameliorative effects of supplemental irrigation and inorganic amendments. Specific objectives were to determine seedling treatment responses during the first (1-0) and second (2-0) growing seasons to:

(1) Ammonium sulfate and ammonium nitrate applied at three and two levels, respectively.

(2) Chelated iron.

(3) Supplemental drip irrigation to reduce soil solute effects and environmental stress.

(4) Interactions among fertilizer and irrigation treatments.

METHODS AND MATERIALS

Two experiments were established in 1982. Expt. 1 was imposed on seedlings sown in May 1981 (Block 1, Sections 28 and 29). Expt. 2 was established in newly prepared beds sown in May 1982 (Block 7, Sections 12 and 13).

Experimental treatments are shown in Table 1. Each 1.2 m by 4.5 m (5.57 m^2) fertilizer treatment plot was replicated three times within sprinkler and sprinkler plus drip main plots. Two N sources were evaluated: ammonium sulfate ($NH4_2SO_4$) applied at 0, 50 and 100 Kg/ha and ammonium nitrate (NH_4NO_3) at 0 and 50 Kg/ha. Chelated iron (EDDHA-Fe) was used as the Fe source. All fertilizers were soil incorporated with a "Planter Junior" fertilizer applicator. Fertilizer nitrogen and EDDHA-Fe were placed 3 cm deep in four bands equally spaced between seedling rows. Iron chelate was thoroughly mixed with fine vermiculite as a vehicle for soil incorporation.

Table 1. Treatments evaluated in all four experiments conducted at the Albuquerque Forest Service Nursery, 1982.

	Fertilizer (Kg/ha)		
Code	$(NH4)_2SO_4$	$(NH4)NO_3$	Chelated Fe
1	0	0	0
2	0	0	25
3	50	0	0
4	50	0	25
5	100	0	0
6	100	0	25
7	0	100	0
8	0	100	25

Phosphorus (0-46-0) was added at the rate of 44 Kg/ha during the preparation of new beds Beginning in June 1982, 50 Kg/ha N were applied at approximately 30-day intervals to reach total amounts applied for each treatment (e.g., 100 Kg/ha of S04-N was applied in two 50 Kg/ha treatments). Chelated iron was applied at 25 Kg/ha Fe with the first N fertilizer treatment.

Irrigation was controlled by an electric valve scheduled by a programmable clock. Supplemental drip irrigation was initially applied through bi-wall lines anchored to the soil surface. Because bi-wall line emitters became partially plugged, they were replaced Aug. 5, 1982 by Rainbird "drip-in" lines (12.7 mm plastic tubing with imbedded emitters). Having larger delivery outlets, drip-in emitters were not plugged with salts and unfiltered irrigation pond algae.

During May and June, 1982, 2-0 and 1-0 plots received an average irrigation output of 7.5 mm and 4.4 mm. Beginning July 7, 1982, seedlings received 3.4 mm of drip irrigation every other day. Drip irrigation was continued until Sept. 10, 1982 when the 2-0 beds were abandoned and irrigation in the 1-0 beds was discontinued. A sharp decline in evaporative demand during August and September promoted soil saturation.

Soil and whole seedling samples were collected from random locations within each plot on Aug. 7-8, 1982. Soil samples were collected from the upper 30-cm of each plot. Ten 2-0 and 20 1-0 seedlings were collected from each plot. Roots were harvested from the upper 25 cm-soil layer. Samples were oven dried at 65 C for 48 hours to obtain root and shoot dry weights. Ten 1-0 seedlings/plot were harvested Sept. 12 and Nov. 4, 1982 to determine root and shoot growth over the summer months. Soils and tissue analyses were performed at the NMSU Soil and Water Testing Laboratory by methods listed in Appendix Tables 1 and 2. Results from soil analyses are in Appendix Table 3.

Data were manipulated as follows: Irrigation treatments (sprinkler and supplemental drip irrigation (SDI)) were considered as experiments in series (Cochran and Cox 1965), then the treatments were partitioned into two factorial analyses: (1) irrigation X S04-N X Fe (2 X 3 X 2) and (2) irrigation X N03-N X EDDHA-Fe (2 X 2 X 2). Plant growth and nutrient responses were examined within 1-0 seedling S04-N and N03-N factorial arrangements. Each treatment combination was given a code number to compare the effects of N sources within the experiment (Table 1). For the 1-0 experiment, effects of time (three sampling dates) were included in the ANOVA structure as a "split plot in time" (Steel and Torrie 1960).

Non-orthogonal contrasts were used to examine plant growth and tissue nutrient responses to specific fertilizer treatments (Table 2). The same contrasts were used to estimate irrigation and fertilizer treatment interactions.

Statistical procedures used to analyze soil and tissue data included: (a) simple correlations, (b) multiple linear regression, (c) analysis of variance and (d) factor analysis. Procedural details for these analyses are reported elsewhere (Cochran and Cox 1957, Steel and Torrie 1960, Neter and Wasserman 1974, and Kennny 1979).

Table 2. Non-orthogonal contrasts used to compare the effects of N source.

Contrast (* Significant)	Description
1	Contrast the effect of N application versus the control (without N), averaged over both irrigation treatments (IT) and Fe levels (0,25 Kg/ha).
2	Contrast the effect of applying 50 units of S04-N versus 100 units of N03-N, averaged over IT and Fe.
3	Contrast the effect of applying 100 units of S04-N versus 100 units off N03-N, averaged over IT and Fe.
4	Contrast the effect of applying 50 units of S04- N in the absence of Fe, averaged over IT.
5	Contrast the effect of applying 50 units of S04-N versus 100 units of N03-N in the presence of Fe, averaged over IT.
6	Contrast the effect of applying 100 units of S04-N versus 100 units of N03-N in the absence of Fe, averaged over IT.
7	Contrast the effect of applying 100 units of S04-N versus 100 units of N03-N in the presence of Fe, averaged over IT.

RESULTS

EXPT. 1: 2-0 SEEDLING GROWTH RESPONSE

Growth Response to Specific Fertilizer Treatments

Expt. 1 was terminated Sept. 10, 1982 because 2-0 seedlings in experimental and adjacent production beds declined as the season progressed. Figs. 1 and 2 show means for seedling biomass and root to shoot (R/S) ratio under specific fertilization and irrigation treatments. Significant

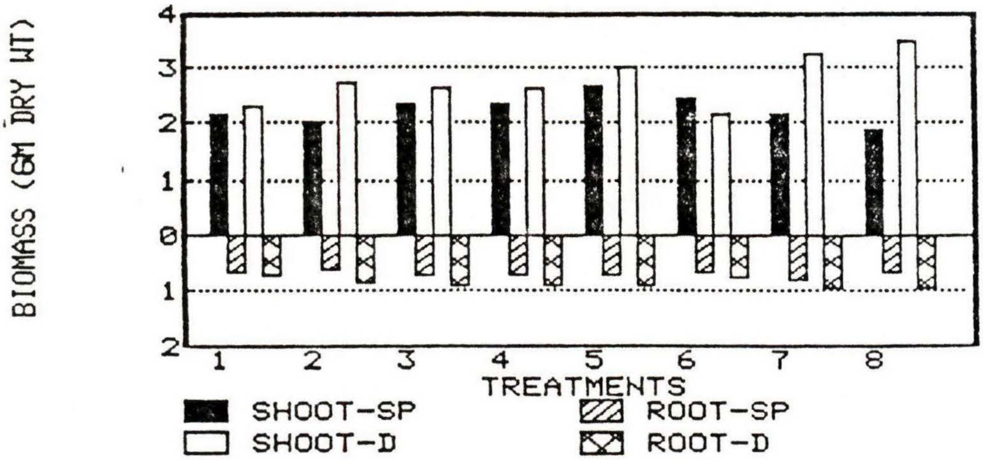


Fig. 1. Expt. 1: 2-0 seedling biomass response to fertilizer and irrigation treatments identified in Table 1. (SP = sprinkler irrigation, D = supplemental drip irrigation). Seedlings were harvested Aug. 7, 1982.

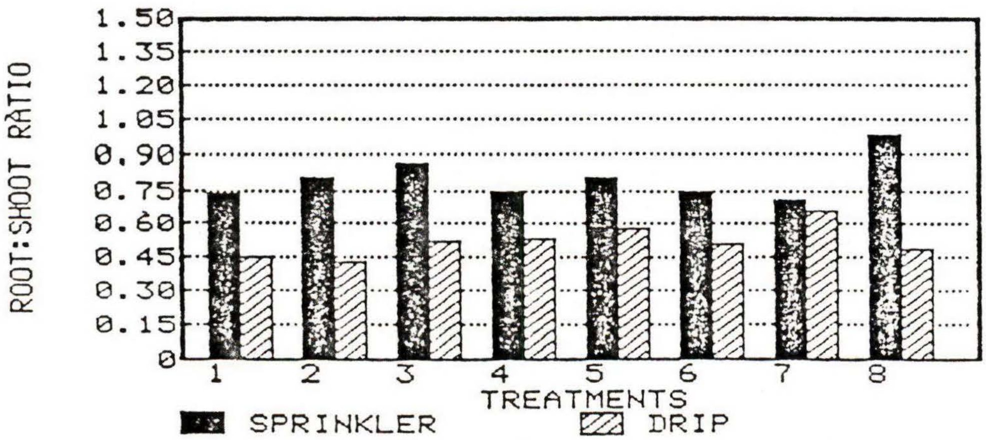


Fig. 2. Expt. 1: 2-0 seedling R/S ratio response to fertilizer and irrigation treatments identified in Table 1. (Drip = supplemental drip irrigation). Seedlings were harvested Aug. 7, 1982.

differences among treatments are discussed under factorial analyses examining main and interaction effects for S04-N and N03-N sources, and non-orthogonal contrasts.

Irrigation X S04-N X EDDHA-Fe Factorial Analysis

Data derived from the Aug. 7, 1982 harvest showed that irrigation main effects were significant for root growth which was 25 % greater in plots receiving SDI (Table 3 and Fig. 3). Shoot growth increased linearly as the S04-N rate increased (Fig. 4). At the maximum S04-N rate, growth was 22% over the control. The interaction between S04-N and Fe was significant (Fig. 5). Without EDDHA-Fe, shoot growth increased slightly at 50 kg/ha S04-N but decreased at the highest S04-N rate. With EDDHA-Fe added, shoot growth was similar at 0 and 50 kg S04-N/ha levels, but at the 100 kg/ha rate showed a 41% increase above the control treatment.

TABLE 3. Significance table showing 2-0 seedling shoot, root and R/S response to S04-N treatments.

Treatment	df	Shoot	Root	Root/Shoot
Rep	2		+	
Irrigation	1		*	
S04-N	2			*
Linear	1	+		
Quadratic	1			+
S04 X Fe	2	+		
Quadratic	1	+		

Significance Levels: + = 0.10, * = 0.05 and ** = 0.01.

Irrigation X N03-N X EDDHA-Fe Factorial Analysis

No significant seedling growth differences were detected among N03-N main or interaction effects.

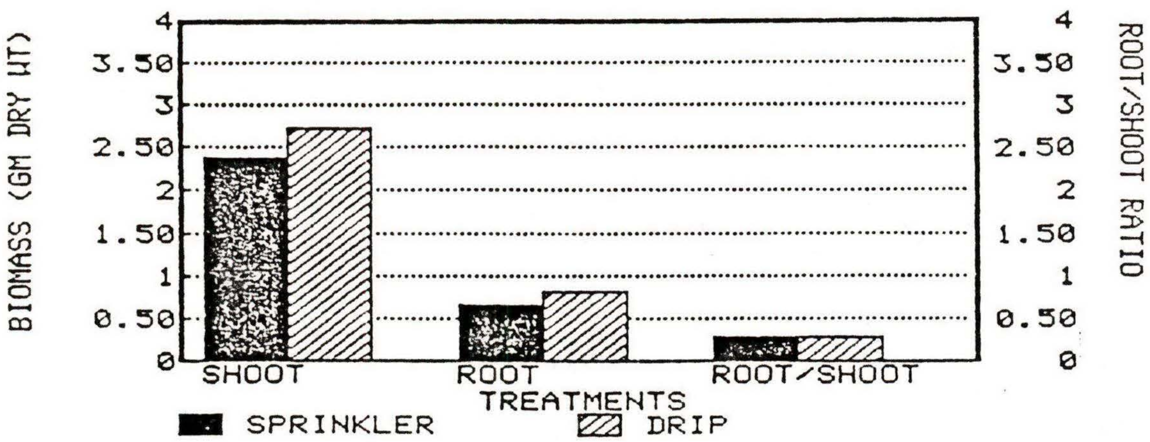


Fig. 3. Expt. 1.: 2-0 seedling biomass response to irrigation treatment effects averaged over S04-N and EDDHA-Fe levels. Seedlings were harvested Aug. 7, 1982.

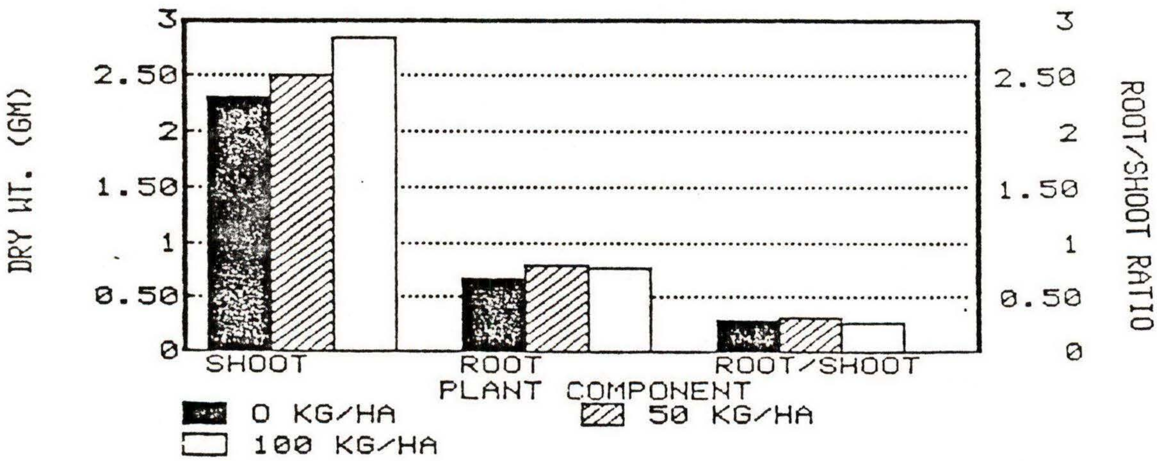


Fig. 4. Expt 1: 2-0 seedling growth and R/S response to S04-N treatment effects averaged over irrigation methods and EDDHA-Fe levels. Seedlings were harvested Aug. 7, 1982.

Non-Orthognonal Contrasts

Table 4 examines significant contrasts. Contrasts showed that: (1) shoot growth was better under the SDI treatment (2) R/S ratio was influenced by the form of N applied in the presence or absence of EDDHA-Fe, and (3) seedling response to fertilizer form was significantly influenced by supplemental irrigation. Specifically, shoot growth was greater under S04-N and root growth was more responsive to N03-N (contrasts 3 and 7). In addition, N03-N produced better shoot growth under SDI and S04-N produced better growth under sprinkler irrigation alone (contrast 6).

Table 4. Significance levels and means among significant contrasts defined in Table 2.

Treatment			Plant Component		
Contrast		df	Shoot	Root	Root/Shoot
	Irrigation (IT)				
	Sprinkler (Spr)	1	2.32 *	0.70	0.30
	Drip		2.85	0.86	0.30
	Treatment (TRT)	1			
3	S04-N 100	1	2.83	0.78	0.28 +
	N03-N 100		2.69	0.84	0.31
7	S04-100+ Fe	1	3.35	0.88	0.26 *
	N03-N 100 + Fe		2.71	0.91	0.34

IT X TRT

		df	Shoot		Root		R/S	
			Spr	Drip	Spr	Drip	Spr	Drip
2	S04-N 50	1	2.36	2.63	0.71	0.87	0.30	0.33 +
	N03-N 100		2.15	3.24	0.78	0.91	0.36	0.28
3	S04-N 100	1	2.67	3.00	0.69	0.88	0.26	0.29 *
	N03-N 100		2.15	3.24	0.78	0.91	0.36	0.28
6	S04-N 100+Fe	1	2.47	2.17	0.63	0.76	0.26	0.35 *
	N03-N 100+Fe		1.87	3.49	0.62	0.93	0.33	0.27

Significance Levels: + = 0.10, * = 0.05 and ** = 0.01. For contrasts 2,3 and 6, + and * indicate significant differences among fertilizer and irrigation treatment combinations.

EXPT. 2 : 1-0 SEEDLING GROWTH RESPONSE

Growth Response to Specific Fertilizer Treatments

Fertilization and irrigation treatment effects on seedling growth are shown in Fig. 6. Treatment means indicate that SDI, Fe and S04-N stimulated growth and that N03-N depressed growth. In addition, the combination of EDDHA-Fe and S04-N produced more growth than S04-N alone. Significant differences among treatments are examined under S04-N and N03-N factorial analyses and non-orthogonal contrasts comparing N-source effects.

Irrigation X S04-N X EDDHA-Fe Factorial Analysis

Significant effects determined within the S04-N factorial analysis are shown in Table 5. Root mass was significantly lower in SDI plots than in sprinkler plots at the first and second harvests, but was not significantly different in SDI and sprinkler plots at the final harvest. However, it is probable that roots mass in SDI plots was underestimated because roots were more fibrous in SDI than sprinkler plots and appeared more extensive at deeper soil depths. The average effect of irrigation treatments on seedling growth is shown in Fig. 7.

Root growth response to fertilization differed under SDI and sprinkler treatments. Under sprinkler irrigation, root mass showed a quadratic trend, increasing from 0 to 50 Kg/ha S04-N and decreasing at the highest rate (Fig. 8). In SDI plots, root mass was similar for 0 and 50 Kg/ha treatments but increased at the 100 Kg/ha rate. EDDHA-Fe effects averaged over S04-N levels are shown in Fig. 9. EDDHA-Fe significantly increased shoot growth after the first harvest. Root growth was similar for 0 and 25 Kg/ha Fe treatments at the final harvest.

The S04-N X EDDHA-Fe interaction showed a significant quadratic response for R/S ratio at the second harvest. Root/ shoot ratio increased at the lowest S04-N rate but decreased at the 100 Kg/ha level. For each S04-N level, the addition of 25 Kg/ha EDDHA-Fe resulted in higher mean values for total seedling biomass but not in significant increases in root or shoot biomass (Fig. 10).

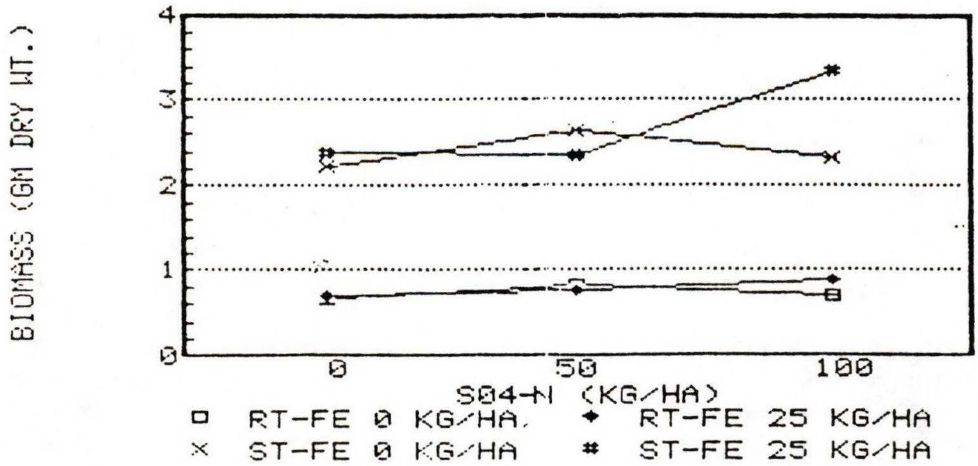


Fig. 5. Expt. 1: 2-0 seedling biomass response to S04-N and EDDHA-Fe treatment combinations. Seedlings were harvested Aug. 7, 1982.

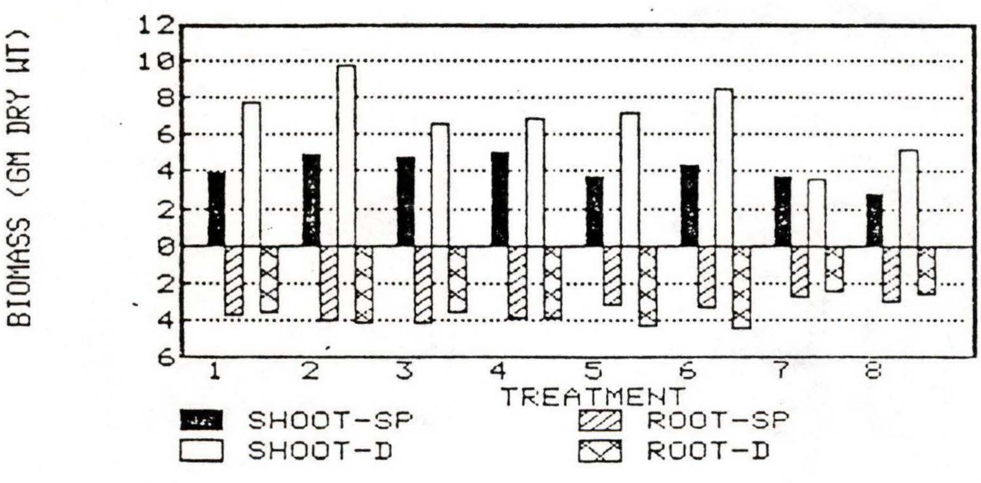


Fig. 6. Expt. 2: 1-0 seedling biomass response to treatments defined in Table 1. Data derived from Nov. 4, 1982 harvest.

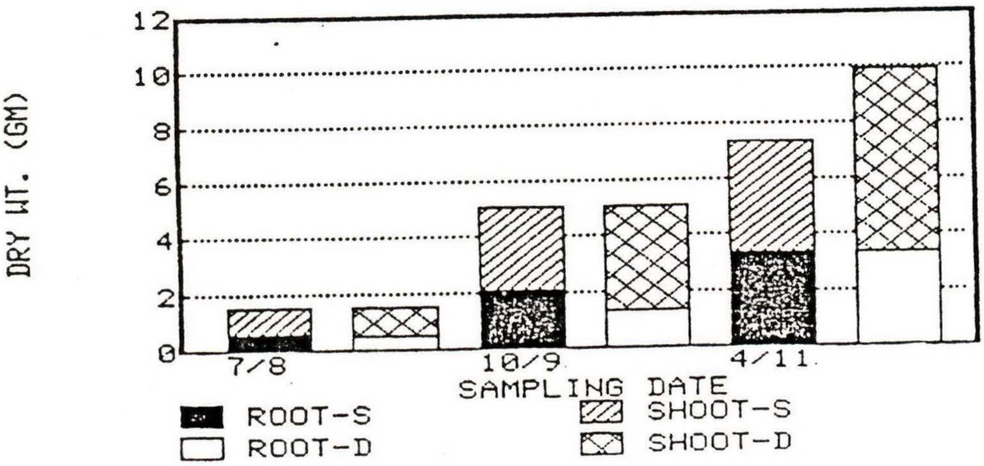


Fig. 7. Expt. 2: 1-0 seedling root and shoot response to drip and sprinkler irrigation effects averaged over SO4-N and Fe levels. Data drawn from Aug. 7, Sept. 10 and Nov. 4, 1982 harvests.

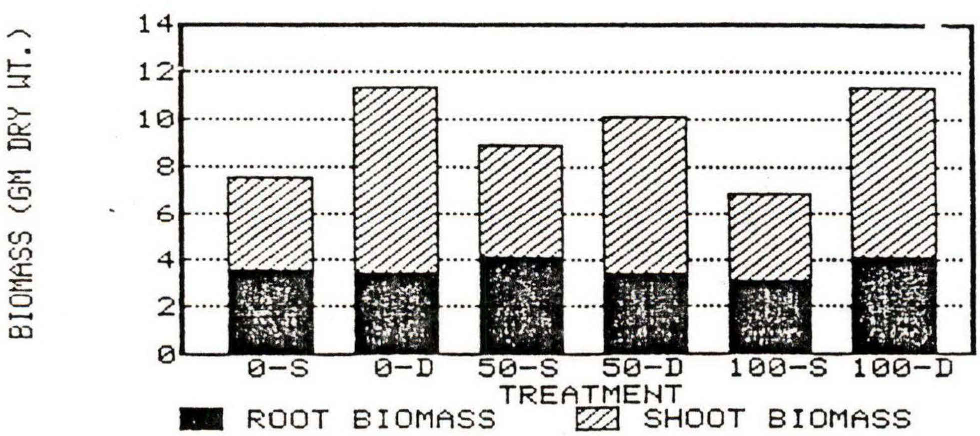


Fig. 8. Expt. 2: 1-0 seedling biomass response to SO4-N and irrigation treatment combinations. Label indicates kg/ha SO4-N applied followed by irrigation method (S= sprinkler, D= drip). Data drawn from Nov. 1982 harvest.

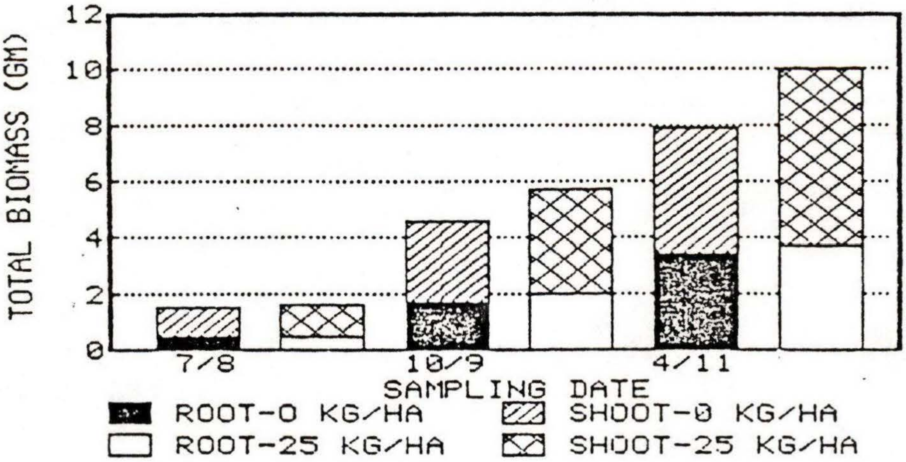


Fig. 9. Expt. 2: 1-0 seedling response to EDDHA-Fe effects averaged over S04-N levels and irrigation treatments. Data drawn from Aug. 7, Sept. 10 and Nov. 4, 1982 harvests.

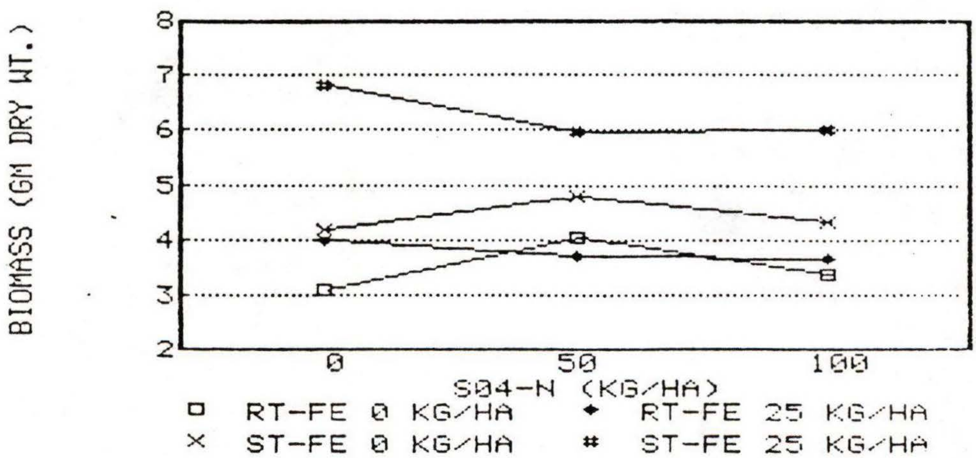


Fig. 10. Expt. 2: 1-0 seedling response to S04-N and EDDHA-Fe effects averaged over irrigation treatments. (RT = root, ST = shoot). Data drawn from Nov. 4, 1982 harvest.

Table 5. Significance table showing 1-0 seedling shoot, root and R/S response to S04-N treatments at each of three sample periods.

		Aug. 7			Sept. 10			Nov. 4		
Treatment	df	S	R	R/S	S	R	R/S	S	R	R/S
Rep	2		*	*		+	*			
Irrigation	1		+	*		**	**			*
S04-N	2					*				
Linear	1					*				*
Quadratic	1									
IT X S04	2			+					*	**
Linear	1									**
Quadratic	1		+	*				+	*	
Fe	1	*		**	**	**		*		**
IT X Fe	1		+							
S04 X Fe	2									
Quadratic	1						**			

Significance Levels: + = 0.10, * = 0.05 and ** = 0.01.

Irrigation X N03-N X EDDHA-Fe Factorial Analysis

Significant effects of N03-N and its treatment combinations on seedling growth are shown in Table 6. Drip irigation markedly increased shoot growth by November, 1982 (Fig 11), as shown by significant differences in shoot growth and R/S ratio: Nitrate N depressed growth after the first harvest (Fig. 12). The interaction of between EDDHA-Fe and N03-N significantly affected shoot growth at all harvest dates. Fig. 13 shows the adverse impacts of N03-N on seedling growth in the presence or absence of EDDHA-Fe.

Non-Orthogonal Contrasts

Significant contrasts are shown in Table 7. In general, seedling growth was greater when S04-N was applied, and 50 Kg/ha of S04-N promoted growth more than 100 Kg/ha of N03-N, with or without EDDHA-Fe (contrasts 2, 5 and 7). Overall, EDDHA-Fe (treatments 2,4,6 and 8) tended to promote growth and N03-N tended to depress growth.

TABLE 6. Significance table showing shoot, root and R/S response to N03-N treatments at each of three sample periods.

		Aug. 7			Sept. 10			Nov. 4		
Treatment	df	S	R	R/S	S	R	R/S	S	R	R/S
Rep	2									
Irrigation	1			*		+	**	*		*
N03-N	1	+			*			+		*
N03-N X Fe	1	**		*	**	*		+		

Significance Levels: + = 0.10, * = 0.05 and ** = 0.01.

Table 7. Levels of significance observed in the analysis of N sources.

Source		df	Shoot	Root	Root/Shoot
Rep		2			*
Irrigation (IT)		1	*	+	**
Treatments (TRT)		7	**	**	*
Contrast	1	1	*	+	
Contrast	2	1	**	*	**
Contrast	3	1	*	+	*
Contrast	4	1			*
Contrast	5	1	**	**	**
Contrast	7	1	**	*	**
IT X TRT		7			
Contrast	2	1			**
Contrast	3	1	+	+	
Contrast	4	1			**
Contrast	7	1	+	+	

Significance Levels: + = 0.10, * = 0.05 and ** = 0.01.

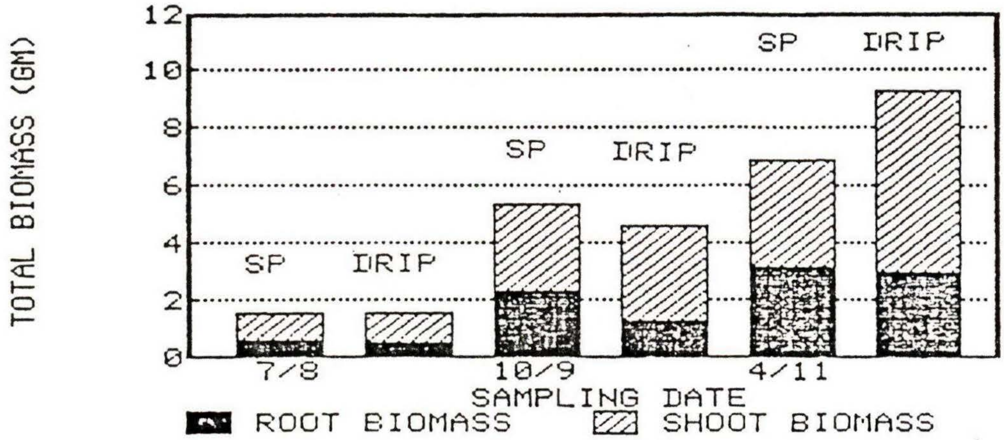


Fig. 11. Expt. 2: 1-0 seedling response to irrigation treatment effects averaged over NO3-N and EDDHA-Fe levels. (SP = sprinkler, DRIP = supplemental drip irrigation). Data drawn from Aug. 7, Sept.10 and Nov. 11, 1982 harvests.

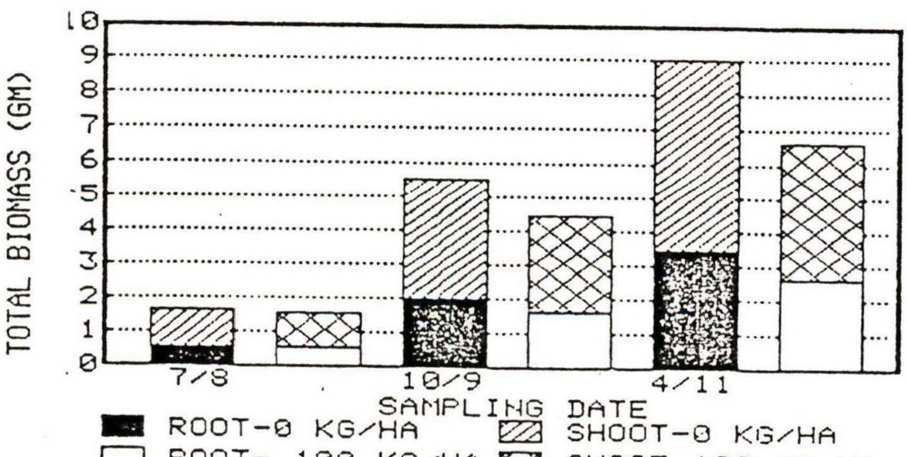


Fig. 12. Expt. 2: 1-0 seedling response to NO3-N treatment effects averaged over irrigation methods and EDDHA-Fe levels. Data drawn from Aug. 7, Sept. 10 and Nov. 4, 1982 harvests.

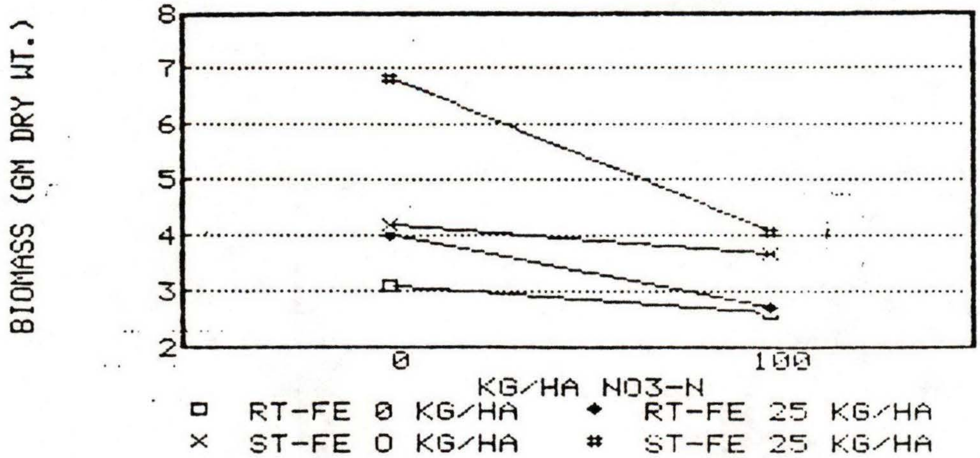
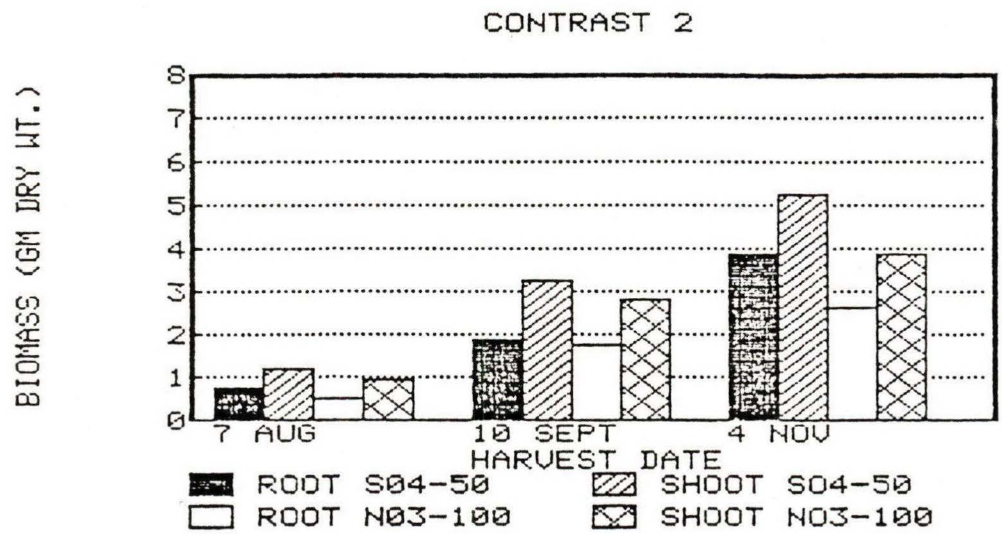
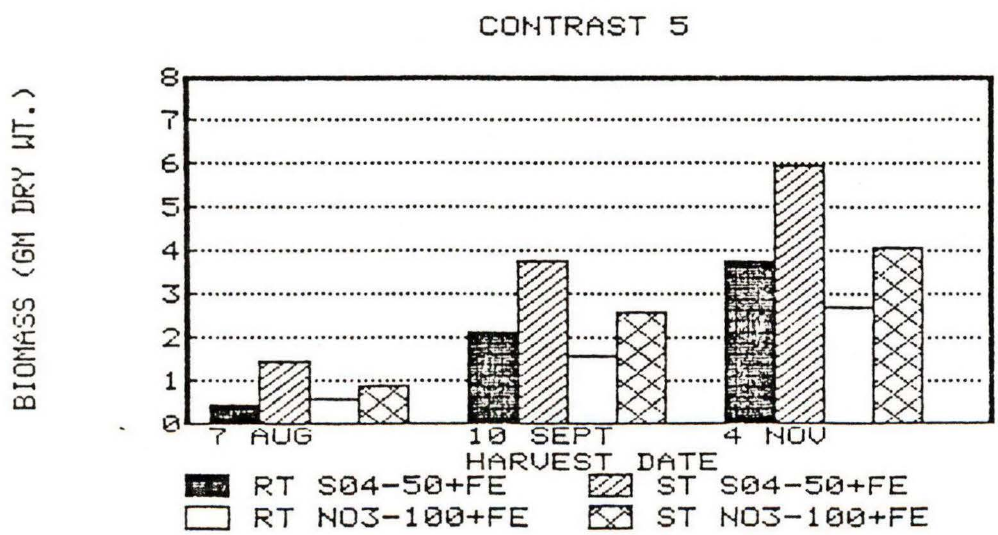
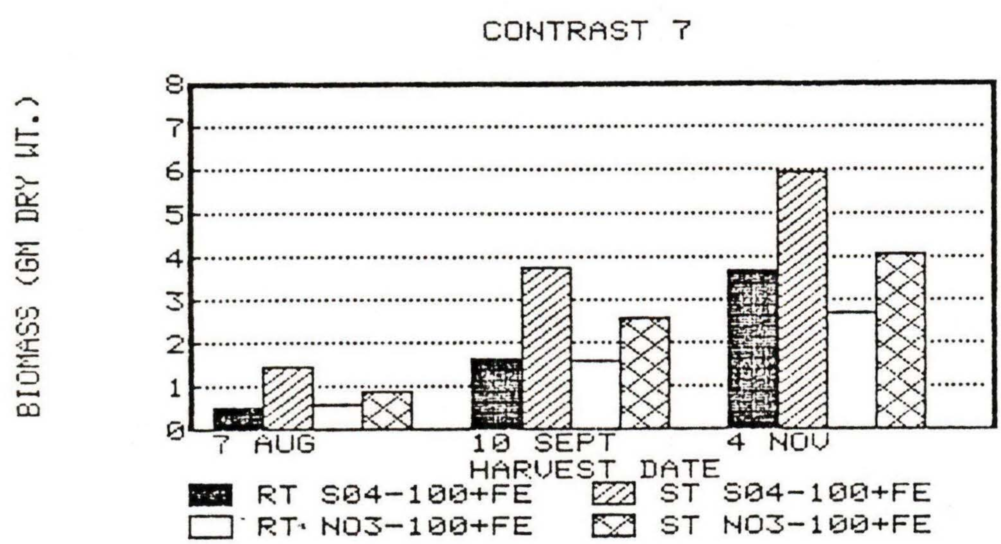


Fig. 13. Expt. 2: 1-0 seedling biomass response to NO3-N and EDDHA-Fe treatment effects averaged over irrigation methods. Data drawn from Nov. 4, 1982 harvest.

Fig. 14. Expt. 2: 1-0 seedling response to SO4-N and NO3-N fertilizers as shown by non-orthogonal contrasts identified in Table 2. Data drawn from Aug. 7, Sept. 10 and Nov. 4, 1982 harvests







SOIL AND 1-0 SEEDLING TISSUE ANALYSIS

Treatment Effects on Soil Chemical Properties

The August 8, 1982 soil chemical condition under each fertilizer and irrigation treatment combination is in Appendix Table 3. Figures 15 and 16 show for SDI and sprinkler treatments the soil chemical condition averaged over fertilizer treatments. Most notable is that SDI significantly reduced soil EC and NO_3.

Relationships Among Soil Variables

Among NO_3-N treated plots, significant (P less than 0.05) positive correlations were found between these soil variables: (1) EC and NO_3 and K, (2) ESP (exchangeable Na percentage) and K (3) organic matter (OM) and Fe, Mn and

$CaCO_3$, and (4) Fe and Mn and $CaCO_3$. Among SO_4-N treated plots, significant positive relationships were found between: (1) OM and P, (2), NO_3 and Zn and $CaCO_3$, (3) P and Mn, and (4) Zn and $CaCO_3$. Significant negative correlations were found between: (1) P and NO_3, Zn, and $CaCO_3$, and (2) K and Zn and $CaCO_3$.

Relationships Between Soil Variables and Tissue Nutrients

Significant correlations (R^2 equal to or greater than 0.8) between soil and tissue variables were as follows: Among NO_3-N treatments, positive correlations were found between: (1) soil NO_3 and root Ca, (2) soil $CaCO_3$ and root Mg and Mn, (4) soil $CaCO_3$ and shoot P, and (5) soil Mn and shoot Zn and Mn. Soil Fe and root P were negatively related. Within SO_4-N treatments, root Ca was negatively related to soil P.

Irrigation Effects on Plant Nutrient Levels

Supplemental drip irrigation caused significantly higher root and shoot tissue elemental concentrations of P, Mg, Na, Mn, B and Al. Averaged over fertilizer treatments, shoot tissue P was 0.18 % for drip plots and 0.12 % for sprinkler plots. Sprinkler irrigated seedlings had much higher concentrations of Ca in roots (9.32 % Ca for sprinkler and 2.63 % Ca for SDI). Root Ca was negatively associated with root N, P, Mg, Mn, Fe, Zn, B, Cu and Al (Table 8). In shoot tissue, Ca was not negatively correlated with other elements (Table 9).

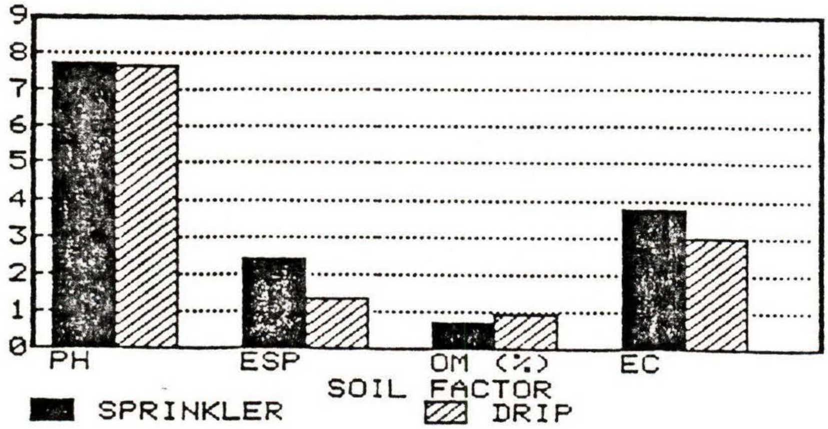


Fig. 15. Soil pH, EC (mmhos/cm), ESP and organic matter content (%) under sprinkler and drip treatments as determined Aug. 7, 1982.

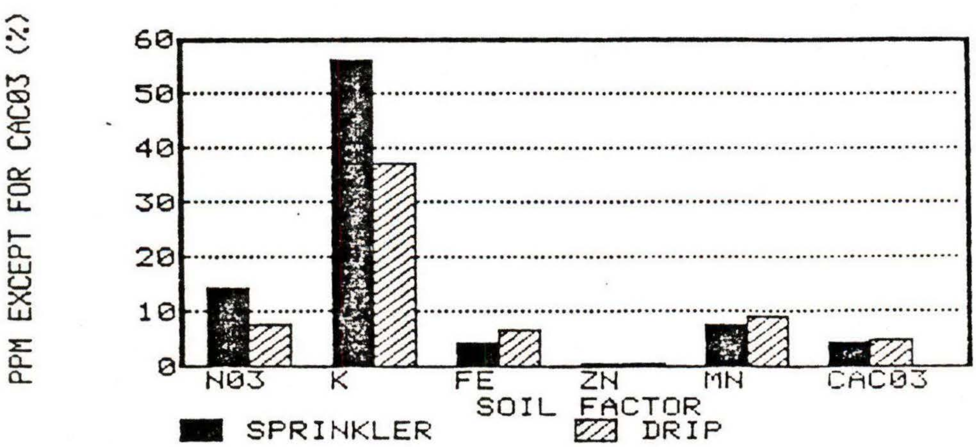


Fig. 16. Soil NO_3(ppm), K (ppm), Fe (ppm), Zn (ppm), Mn (ppm) and $CaCO_3$ (%) under sprinkler and drip treatments as determined Aug. 7, 1982.

Table 8. Correlation matrix for root elements. Data were drawn from SO4-N factorial analysis.

Significant (P less than 0.05) positive correlations are indicated by +, negative correlations by -. Zero indicates no correlation at the 0.05 level.

	N	P	K	Mg	Ca	Mn	Fe	Zn	Na	B	Cu	Al
N		+	+	0	-	0	0	0	0	+	0	0
P			+	+	-	+	+	+	0	+	+	+
K				+	0	+	+	+	0	+	+	+
Mg					-	+	+	+	0	+	+	+
Ca						-	-	-	0	-	-	-
Mn							+	+	0	0	+	+
Fe								+	0	0	+	+
Zn									0	+	+	+
Na										0	+	+
B											0	0
Cu												+
Al												

Table 9. Correlation matrix for shoot elements. Data were drawn from S04-N factorial analysis.

Significant (P less than 0.05) positive correlations are indicated by +, no correlation by 0.

	N	P	K	Mg	Ca	Mn	Fe	Zn	Na	B	Cu	Al
N		0	0	0	0	0	0	0	0	0	0	0
P			+	+	0	+	0	+	0	+	0	0
K				0	0	+	0	+	0	+	0	0
Mg					+	0	+	0	0	0	+	+
Ca						0	+	0	+	0	0	+
Mn							0	+	0	0	0	0
Fe								0	+	0	0	+
Zn									0	+	+	0
Na										0	0	+
B											+	0
Cu												0
Al												

Although ion imbalances conducive to lime-induced chlorosis were found under both irrigation treatments, the Ca to Mg ratio was much smaller under SDI (2.03:0.19) than sprinkler (5.36:0.13) irrigation. Morrison (1974) recommends for conifers a 1.5:1.2 ratio between Ca and Mg.

Tissue concentrations of the following elements were significantly greater in roots than shoots: K, Ca. Mg, Na, Fe, Zn, Cu and Al. Nitrogen and P were more concentrated in shoots.

Nitrogen Fertilization Effects

Nitrate N fertilizer increased the level of soluble salts, while the addition of S04-N had no detectable influence on soil EC. Soil EC was positively related to shoot Ca concentration and negatively related to shoot P, K, Mg, Zn, Mn, B, Cu and Al. In root tissue, EC was positively correlated with Ca and negatively related to P, K, Mg, Zn, Mn, B, Cu and Al.

Compared against standards recommended by Morrison (1974) and Landis (1985), shoot tissue nutrient levels were adequate for all elements. However, the Ca level reported adequate by Morrison (0.20 to 0.50 % dry wt.) was exceeded five times under SDI and ten times under sprinkler irrigation. According to Contrast 1, the addition of N resulted in no significant change in tissue N. Within factorial partitions, however, the addition of N03 increased tissue N. Ammonium sulfate had no significant effect on tissue N, P or Fe.

Within the S04-N analysis, the addition of Fe increased tissue Fe from 1.41 to 1.59 % and the S04-N X Fe interaction was significant. Tissue N was highest when Fe applied at 25 Kg/ha was combined with 50 Kg/ha S04-N (Fig. 17). Within the N03-N analysis, Fe resulted in no significnt change in tissue Fe.

Contrast 1 showed that N fertilization increased tissue Ca, Mg and Fe. Zinc was higher when S04-N was applied at 50 Kg/ha than when N03-N was appplied at 100 Kg/ha (Contrasts 2 and 4). Shoot tissue Ca and Fe were higher in N03-N treated seedlings than in those fertilized with S04-N (Contrasts 3 and 7).

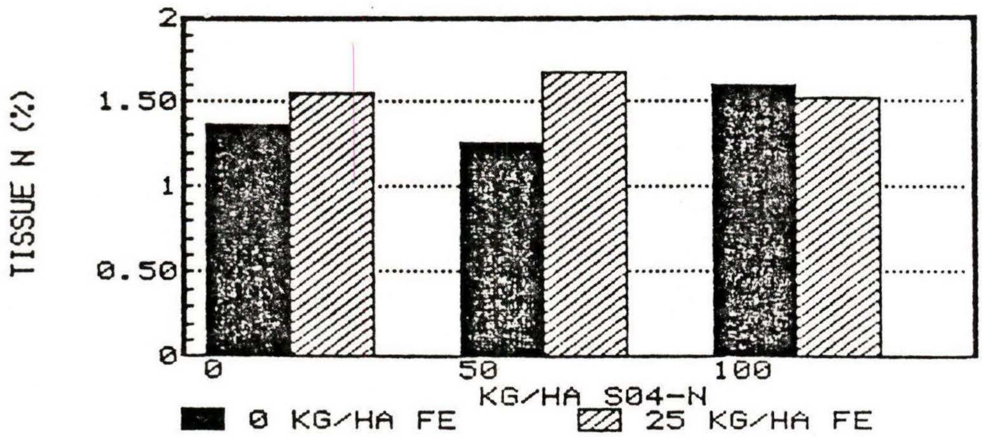


Fig. 17. Effect of S04-N and EDDHA-Fe interaction on shoot tissue N level. Data drawn from Aug. 7, 1982 seedling harvest.

DISCUSSION AND CONCLUSIONS

Essentially, Expt. 1 showed that supplemental drip irrigation improved root growth, and that seedling shoot growth was best when EDDHA-Fe was combined with 50 kg/ha S04-N. In addition, shoot growth was favored by S04-N but root growth by N03-N. More information was gained from Expt. 2 because seedlings were initially uniform and more responsive to treatments. In Expt. 2, 1-0 seedlings consistently responded poorly to N03-N, but positively to drip irrigation, Fe and S04-N. Seedling root growth was best at the 50 kg/ha S04-N rate under sprinkler and the 100 kg/ha rate under drip.

Soil and tissue analyses correlate with many of the observed treatment responses. Supplemental irrigation consistently reduced soil EC and N03 and seedling calcium content, particularly root Ca. Soil EC and root Ca reduced the uptake of most of elements. Overall, SDI improved seedling nutrition, evidenced by improved growth and higher tissue nutrient concentrations. Under SDI, roots responded favorably to the highest rate of S04-N which apparently damaged sprinkler irrigated roots due to solute effects. Soil pH was unaffected by experimental treatments, apparently because the soil is heavily buffered by calcium carbonate.

Calcium emerged as a dominant factor within the complex of variables studied. Seedling growth clearly suffered under treatments which failed to directly reduce root Ca or to indirectly ameliorate Ca effects on seedling physiology. The beneficial effects of SDI, S04-N and Fe can be linked to reductions in the adverse effects of excess Ca. The adverse impacts of N03-N on seedling growth can be linked to solute effects and to alkalization effects in the root zone.

Specifically, high Ca concentrations around and in roots formed a chemical barrier limiting the uptake of soil nutrients (Mortvedt et al. 1977). This is supported by negative correlations between root Ca and most of the elements studied. Landis (1980) reported that soluble Ca is the predominant soil cation at the nursery and that soil EC increases in a curvilinear manner as the Ca concentration increases. It follows that soluble Ca may directly damage root through soil solute effects.

The adverse impacts of N03-N and positive effects of S04-N can be traced to their influences within the root zone. As noted by Mengel and Kirkby (1982), the assimilation of N03 after uptake leads to an alkalization effect in the plant resulting in organic anion accumulation and to excess uptake

of cations (e.g., Ca). In contrast, plants supplied with NH_4-N often contain lower concentrations of inorganic cations. Essentially, NH_4^+ is taken up in exchange for H^+, resulting in the acidification of the nutrient medium. Under conditions where nitrification can occur, the application of NH4 -fertilizers has the same effect as acidifying soil and leaching Ca. Thus for every 100 kg $(NH_4)_2SO_4$ added to the soil about 45 kg Ca are removed in drainage water (Mengel and Kirkby 1982).

Iron deficiencies are most common in calcareous soils and are particularly troublesome in arid soils cropped to high -iron demand plants (e.g., nursery trees and shrubs). Solubility and mobility are the keys to plant Fe deficiency because in alkaline soil, Fe is present in large quantities as insoluble iron oxides, carbonates, phosphates and hydroxides which may be unavailable to plants. In this study, EDDHA-Fe apparently counteracted the negative impact of Ca on Fe availability, possibly within the plant as well as in the soil solution. This is supported by better seedling growth reflecting more total Fe uptake per seedling.

EDDHA-Fe did not not substantially increase tissue Fe concentration and by published standards was adequate across treatments. However, it is important to recognize that leaf Fe analysis often does not indicate Fe deficiency, because Fe deficiency symptoms are often caused by Fe inactivation in the plant rather than inadequate Fe uptake. Wallace et al. (1976) suggested that a cation-anion imbalance in chlorotic plants causes plant pH to increase resulting in Fe precipitation and inactivation within the plant. In this vein, there is now evidence that Fe chlorosis found on calcareous soils results primarily not because of low soil Fe availability, but because of a physiological disorder induced by excess HCO_3^-. Abundant HCO_3^- in the root medium results in Fe immobilization in the plant (Mengel et al. 1979). This supposition is consistent with the observation that Fe chlorosis is more likely to appear when plants are fed NO_3 than with NH_4-N (Machold 1967).

RECOMMENDATIONS

Results and findings from this study lead to the following recommendations:

(i) Schedule and manage irrigations precisely to minimize soil Ca and EC effects.

A pan evaporation station should be installed. The nursery staff must know daily pan evaporation rates to determine the irrigation levels required to minimize effects of soluble Ca in the root zone. The use of salinity sensors would be

helpful in monitoring irrigation effects. Properly scheduled irrigation can also reduce environmental heat and moisture stress indirectly affecting Ca uptake. To a large extent, the intensity of transpiration controls the passive uptake and translocation of Ca. Factors governing transpiration also influence Ca uptake and translocation.

Overwatering must be avoided because bicarbonate ions accumulate in waterlogged soils and cause reductions in plant Fe (Mengel et al. 1979). The rise in bicarbonate is probably the reason for the observed enhanced chlorotic symptoms on calcareous soils after wetting or irrigation.

(ii) Apply Fe chelates.

EDDHA is the most stable complex in the range of pH found in calcareous soils and should be the choice treatment. Because fast-acting foliar chelate sprays are usually not effective very long, several applications per growing season may be necessary. Soil applications last longer but act slower and require five to fifteen times more chelate.

(iii) Apply NH4-N fertilizers; avoid NO3-N.

This study showed the 50 kg/ha SO4-N rate to be the best under the conditions of the study.

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APPENDIX TABLES

APPENDIX TABLE 1. Components and procedures used for soil analyses conducted at the NMSU Soil, Plant and Water Laboratory, 1982.

Component	Procedure	Reference
Organic Matter	Walkley - Black	Black, 1965
Soil Reaction (pH)	Saturated Paste	Richards, 1954
Salinity (EC)	Resistance Cup	Richards, 1954
Exchangeable Na % (ESP)	SAR estimation	Richards, 1954
Texture	By Feel	
NO3	Cd Reduction Column	EPA, 1974 Ludwick & Reuss, 1974
P	Molybdo-blue, 1.5	EPA, 1974
K	Flame Emission	EPA, 1974
$CaCO_3$	Rapid Titration	USDA, 1972
Fe	DTPA Extract	Ludwick & Reuss, 1974
Zn	DTPA Extract	" "
Mn	DTPA Extract	" "

APPENDIX TABLE 2. Components and procedures used for tissue analyses conducted at the NMSU Soil, Plant and Water Laboratory, 1982.

Component	Procedure	Reference
N	Kjeldahl	Black, 1965
P	ICAP	AOAC, 1980
K	Flame Emission	EPA, 1974
Ca	ICAP	AOAC, 1980
Mg	ICA	AOAC
Fe	ICAP	AOAC, 1980
Mn	ICAP	AOAC, 1930
Zn	ICAP	AOAC, 1980
B	ICAP	AOAC, 1980
Cu	ICAP	AOAC, 1980
Al	ICAP	AOAC, 1980
Na	Flame Emission	EPA, 1974

Appendix Table 3. Soil chemical condition under fertilizer treatments defined in Table 1 as determined Aug. 8, 1982.

SOURCE	Treatment Number							
	1	2	3	4	5	6	7	8
Sprinkler Irrigation								
pH	7.75	7.71	7.74	7.74	7.62	7.73	7.64	7.72
EC (mmhos/cm)	3.60	3.56	4.03	3.42	3.81	3.93	3.79	4.18
ESP	2.53	2.00	3.20	2.53	2.90	1.93	1.50	2.90
OM (%)	0.69	0.63	0.54	0.77	0.78	0.93	0.75	0.76
P (ppm)	12.2	13.2	10.5	14.1	10.8	10.6	20.4	18.3
NO_3^- (ppm)	8.80	3.47	3.75	8.50	10.67	40.33	29.47	11.13
K (ppm)	60.1	48.9	74.3	43.7	60.3	44.4	45.6	72.3
Zn (ppm)	0.82	0.59	1.84	0.64	0.63	1.82	0.59	0.54
Fe (ppm)	3.64	4.64	3.15	4.52	4.40	5.97	5.51	4.86
Mn (ppm)	7.32	6.89	7.36	7.70	8.24	7.69	8.59	10.04
$CaCO_3$ (%)	4.40	3.77	3.95	4.83	5.00	5.17	4.6	5.23
Drip + Sprinkler Irrigation								
pH	7.78	7.71	7.68	7.68	7.63	7.65	7.71	7.68
EC (mmhos/cm)	2.60	3.25	3.09	3.48	2.54	3.15	2.88	3.43
ESP	1.30	1.83	0.83	1.23	1.45	1.43	1.60	1.47
OM (%)	0.97	0.99	1.03	0.80	1.24	0.92	0.74	0.84
P (ppm)	12.6	13.1	16.1	10.7	14.0	7.6	11.8	10.3
NO_3^- (ppm)	1.23	2.47	7.67	9.27	8.05	14.83	7.60	12.20
K (ppm)	31.9	43.7	43.0	46.3	34.2	33.4	28.0	39.8
Zn (ppm)	0.63	0.60	0.52	0.73	0.53	0.50	0.64	0.48
Fe (ppm)	7.04	10.16	6.65	5.36	7.75	6.37	7.20	6.52
Mn (ppm)	9.16	9.48	10.80	7.89	11.33	6.87	9.19	8.64
$CaCO_3$ (%)	5.37	4.76	5.03	4.63	5.45	5.27	5.73	4.93